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BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Effects of Mission Mode and Crew Size on Weight-in-Earth-Orbit for a Mars Landing Mission
Case 720

DATE: November 6, 1967

FROM: H. S. London

ABSTRACT

The effects of mission profile and crew size selection on the weight-in-Earth-orbit requirement are quantitatively investigated for a sample manned planetary mission (1982 manned Mars landing). The differences between relatively ambitious missions and a very minimal mission are shown to be quite profound, and in fact can imply an order of magnitude difference in launch requirements.

The results suggest the possibility of carrying out a Mars landing mission with two slightly up-rated Saturn V's and all-chemical spacecraft propulsion, based upon spacecraft weight estimates from other Bellcomm studies (References 3 and 4), a two or three-man crew, and the use of Venus swingby mode plus elliptical parking orbit at Mars. While some of the assumptions necessary to reach this radical a conclusion may or may not prove acceptable, the results at least dramatically indicate that it should be possible to construct a relatively cheap small-scale manned planetary program if one sets out with that objective in mind.

(NASA-CR-93132) EFFECTS OF MISSION MODE AND CREW SIZE ON WEIGHT-IN-EARTH-ORBIT FOR A MARS LANDING MISSION (Bellcomm, Inc.) 10 p

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MEMORANDUM FOR FILE

Introduction

The selection of mission mode, which determines ΔV requirements, and crew size, which to a large extent determines spacecraft weight, have a very pronounced effect on the initial weight-in-Earth-orbit (WIO) requirements for manned planetary missions. Many studies of Mars landing missions, e.g., have been based on the use of low-altitude circular parking orbits at Mars and crews of six-twelve men. Ground rules along these lines generally lead to the conclusion that nuclear rocket spacecraft stages and grossly up-rated launch vehicles (along with essentially new launch facilities) are basic requirements for a manned planetary program. If, however, one is willing to scale down the mission and design the spacecraft such that it can be handled by a relatively small crew and accept mission profile compromises such as using elliptical parking orbits (resulting in some degradation in orbital reconnaissance) and Venus swingby (which increases mission duration), the propulsion requirements diminish to the point where missions can be reasonably carried out with all-chemical spacecraft propulsion. That is to say that the WIO requirement is small enough to be accommodated with a relatively small number of "product-improved" or even standard Saturn V launch vehicles.

It is the purpose of this memorandum to present quantitative estimates of the effects of mission profile and crew size on WIO for a sample mission: a 1982 all-chemical Mars landing.

Mission Model

The basic mission model assumes departure from a low-altitude circular orbit at Earth, propulsive braking at Mars, descent of an excursion module to the surface of Mars eventually followed by rendezvous in orbit with the main spacecraft, propulsive departure from Mars after jettisoning the excursion module, and entry into the Earth's atmosphere at a speed not exceeding 55,000 fps.

Weight calculations were based on the assumption of tailored stages, i.e., the propellant capacity of the Earth departure, Mars capture and Mars escape stages are each sized to the particular ΔV requirement and are in general different.

The effects of the following mission profile variations were studied:

1. Venus swingby versus direct Mars-Earth return leg

2. Highly eccentric (~1-2 1/2 day period) parking orbit versus low-circular orbit at Mars

3. Direct entry of the MEM (Mars Excursion Module) from hyperbolic approach; i.e., separation from the mission module before entering the Mars capture orbit, versus orbital entry

4. "Long" versus "short" outbound leg, i.e., about 60 days longer duration in this case

Mission ΔV's were selected to allow for approximately twenty day launch windows at both Earth and Mars. The ΔV budgets were as follows (for circular orbits):

<u>Earth-Mars Leg</u>

Earth escape = 13,300 fps, short leg
Earth escape = 12,450 fps, long leg
Midcourse = 500 fps
Mars capture = 9,000 fps, short leg
Mars capture = 7,600 fps, long leg

<u>Mars-Earth</u>

Mars escape = 15,600, Venus swingby
Mars escape = 18,300, direct
Midcourse = 500 + 500 = 1,000 fps, Venus swingby
Midcourse = 500 fps, direct

Earth retro prior to entry = 0, Venus swingby (since entry speeds are below 50,000 fps).

Earth retro = 5,000 fps, direct (for entry at 55,000 fps).

Elliptical capture orbits at Mars are assumed to require 4,200 fps less ΔV for both capture and escape. This corresponds to an orbit period of about 2 1/2 days (eccentricity = .9) with the same ΔV reserves as for circular orbits. This is judged to be about the maximum eccentricity orbit of interest; adding about 400 fps to the capture and escape maneuvers would bring the orbit period down to 1 day.

Cryogenic stages with Isp of 460 seconds and $\lambda = .88$ were assumed for Earth escape, Mars capture and Mars escape. Propellant boiloff of two percent was assumed for the Mars capture and escape stages. The midcourse and Earth retro stages were assumed to have Isp = 390 seconds and $\lambda = .85$.

Calculation of WIO Sensitivities

It can be shown that for fixed ΔV's and stage mass fractions (λ's), the WIO is exactly linear with respect to each of the spacecraft module weights. Therefore, rather than actually calculating the parametric variations of WIO with all the different module weights, it is only necessary to calculate the partial derivatives of WIO with respect to each module weight. For fixed ΔV's and λ's, therefore, the WIO can be expressed as

$$WIO = a_1 W_{eem} + a_2 W_{mm} + a_3 W_{mem} + a_4 W_{vp}$$

where the above weights designate earth entry module, mission module, Mars excursion module, and (in the case of Venus swingby missions) a Venus payload module. These partial derivatives were calculated using the computer program described in References 1 and 2.

Estimated variations in spacecraft weights with crew size are given in Reference 3. Combining these variations with the WIO partial derivatives, one can then arrive at WIO variations with crew size for each mission profile.

Spacecraft Weight Estimates

Reference 3 gives estimated variations in spacecraft weight with crew size for a 700 day mission. Maximum and minimum estimates are given as well as baseline values; only the baseline figures are used herein.

For the 700 day mission the data of Reference 3 can be represented as follows:

Earth entry module $\approx$ 3700 lb/man

Mission module $\approx$ 10,000 lbs + 8,000 lb/man

Comparable estimates of MEM weight as a function of crew size are not available. However, a minimum-weight concept for a two-man MEM has been analyzed in Reference 4; this study indicates that by designing the ascent capsule "solely to provide transportation from the surface of Mars to a parent capsule in parking orbit", the gross weight of a two-man capsule can be held to about 1400 pounds. Assuming the use of advanced Earth-storable propellants ($I_{sp} \approx 340$ seconds) for the ascent stages and that (on the basis of entry vehicle studies) the gross separation weight of the MEM is conservatively about three times the gross ascent vehicle weight, the MEM gross weight should be under 40,000 pounds for elliptical parking orbits and roughly sixty percent of that for ascent to circular orbit.

Small probes plus enroute experiments are called out as a separate item in Reference 3. Because of the speculative nature as well as the relatively small total weight of these items, however, they are considered herein to be lumped with other module weights.

Results

The WIO sensitivities to module weights for the 1982 Mars landing mission are given in Table I, where again

$$\text{WIO} = a_1 W_{eem} + a_2 W_{mm} + a_3 W_{mem} + a_4 W_{vp}$$

These results illustrate the profound effect of mission profile on WIO. Contrasting the most difficult and easiest missions (the first and last cases in the table), the differences are a factor of better than five with respect to entry module weight, better than three with respect to mission module weight, and better than two with respect to excursion module weight.

TABLE I

Return Leg		Outbound Leg		Mars Parking Orbit		MEM Separation		a_1	a_2	a_3	a_4
D	VSB	S	L	C	E	BMC	AMC	(lbs/lb)			
X		X		X			X	57.9	35.5	6.45	--
X		X			X		X	25.9	15.9	4.52	--
	X	X		X			X	27.7	27.7	6.45	26.4
	X	X		X		X		27.7	27.7	3.07	26.4
	X	X			X		X	12.9	12.9	4.52	12.3
	X	X			X	X		12.9	12.9	3.07	12.3
	X		X		X		X	10.5	10.5	3.74	10.0
	X		X		X	X		10.5	10.5	2.85	10.0

D - Direct
VSB - Venus Swingby
S - Short
L - Long
C - Circular
E - Elliptical
BMC - Before Mars Capture
AMC - After Mars Capture

The low sensitivity to MEM weight, as compared with other modules, indicated in Table I is somewhat more pronounced in the 1982 mission than in general because of the low Mars arrival speed and substantially higher departure speed associated with this particular year. In many other mission opportunities the arrival and departure speeds are more evenly matched and in other cases the arrival speed is substantially higher than the departure speed. In those years sensitivity to MEM weight and the effect of MEM separation prior to orbit capture will be somewhat greater.

The above results can be combined with the entry module and mission module weight estimates given in the previous section.

Assuming a two-man MEM with a gross separation weight of 40,000 pounds in the case of elliptic parking orbits or 24,000 pounds for low altitude circular orbit, and arbitrarily assuming that 10,000 pounds of Venus probes are carried on Venus swingby missions, the following WIO's are obtained:

TABLE II

Return Leg		Outbound Leg		Mars Parking Orbit		MEM Separation		Weight in Earth Orbit, Pounds
D	VSB	S	L	C	E	BMC	AMC	N = Crew Size
X		X		X			X	509,800 + 498,230 N
X		X			X		X	267,480 + 223,030 N
	X	X		X			X	695,800 + 324,090 N
	X	X		X		X		614,680 + 324,090 N
	X	X			X		X	432,800 + 150,930 N
	X	X			X	X		374,800 + 150,930 N
	X		X		X		X	354,600 + 122,850 N
	X		X		X	X		319,000 + 122,850 N

D - Direct
VSB - Venus Swingby
S - Short
L - Long
C - Circular
E - Elliptical
BMC - Before Mars Capture
AMC - After Mars Capture

These figures show how small the launch requirements can become by minimizing crew size in addition to choosing low ΔV missions. For example, the "conventional" mission involving circular parking orbit at Mars and a crew size of, say, six-eight men requires 3.5 - 4.0 x 10^6 pounds WIO for the direct mission or about $2.6 - 3.1 \times 10^6$ pounds for Venus swingby ($2.3 - 2.8 \times 10^6$ pounds if no Venus probes are carried) according to the figures in Table II.

Using the easiest mission on the other hand (the last case in Table II), the WIO drops to about 1.3×10^6 pounds, requiring 4-5 Saturn V launches for an eight-man crew. Consider moreover dropping to a minimal crew size for the same mission profile. With a three-man crew, the WIO is only about 678,000 pounds, and 100,000 pounds of this is attributable to an assumed Venus payload of 10,000 pounds. Therefore, the three-man mission, would, assuming the spacecraft weight estimates of References 3 and 4, be within the weight capacity of two product-improved Saturn V's. To carry it one step further, a two-man mission would require 470,000 - 570,000 pounds WIO with 0-10,000 pounds of Venus payload, and could therefore be carried out with two standard or only slightly improved Saturn V's.

These data have been derived with a manned landing on Mars in mind; however they can just as well be interpreted as applying to manned orbital reconnaissance of Mars with probes being deployed at Mars rather than a manned excursion module.

Conclusions

The details of the mission profile and the crew size for a given mission have a profound effect upon total requirements for manned planetary capture/landing missions.

By keeping to the easier mission profiles (particularly the use of elliptical parking orbit at Mars and the use of Venus swingby during unfavorable opposition years), minimizing crew size, and adhering closely to minimum-weight spacecraft design by limiting the functional requirements imposed on spacecraft modules and subsystems as well as utilizing technology advances (as discussed in References 3 and 4), spacecraft propulsion requirements can be held down to the point where missions can very reasonably be performed with all-chemical propulsion and Saturn V launch vehicles.

The data used in this study suggest the possibility of carrying out a manned Mars landing mission (or alternatively a manned orbital reconnaissance mission including about 40,000 pounds of Mars probes) with only two product improved Saturn V's carrying a two or three-man crew, or with four or five such launch vehicles with as much as an eight-man crew.

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H. S. London

for H. S. L.

Attachment
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